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SUBMARINE CREW EFFECTIVENESS DURING SUBMERGED MISSIONS OF SIXTY OR MORE DAYS' DURATION

by

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13 ABSTRACT

The primary objective of this study was to integrate that segment of the literature of submarine psychology which focusses upon the major factors affecting submarine crew-member effectiveness during prolonged submergence. First, the most significant submarine stressors were delineated together with the specific adaptive processes correlated with them. These were found to be: Confinement, revitalized air, flattening of circadian rhythms, threat of hyperbaric exposure and sleep deprivation. Performance decrements, incidence of debilitating morbidity (including psychopathology), and decompensatory trends in crew morale appeared to be minimal during long cruises. In general, the impressions from this integrative review of this rather-specialized literature is that the habitability situation in the submarine service continues to be optimal, in part because of the effective psychiatric screening procedures in force, but also as a result of the quality of leadership demonstrated by the officers and petty officers making up the crews of the submarines in the fleet.

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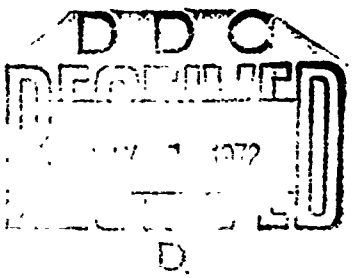

SUMMARY PAGE

THE PROBLEM

To integrate that segment of the literature of submarine psychology which focusses on the major problems related to the effectiveness of crewmembers during prolonged submerged submarine cruises.

FINDINGS

The common denominator across some 36 rather narrowly focussed papers in this field was the finding that there are remarkable individual differences in the capacity to adjust to long submergence. Thus, the efficacy of submariner selection procedures becomes a paramount consideration in attaining and maintaining an efficient submarine service. In this study, performance decrements, incidence of debilitating morbidity (including psychopathology) and decompensatory trends in crew morale appeared minimal. Certain hypothetical factors, such as efficient screening techniques and high-quality group leadership are suggested as causally related to this optimistic appraisal of submarine crew effectiveness as a whole.

APPLICATIONS

This integrative summary of the literature dealing with the major factors related to submariner effectiveness argues strongly for the relevance of a dynamic psychiatric screening program. By delineating the major classes of submergence stressors, it suggests specific adaptive mechanisms which may be optimized by proper human engineering and ship design.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2071DXC9 – Identification of the Major Factors Affecting the Performance, Safety and Health of Navy Divers. The present report is No. 1 on this Work Unit. It was approved for publication on 28 October 1971 and designated as Naval Submarine Medical Research Laboratory Report No. 686.

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ABSTRACT

The major objective of this study was to integrate that section of the literature of submarine psychology which is concerned with the major factors affecting the performance of submarine crew members during prolonged submerged cruises.

First, the major submarine stressors were delineated, together with the specific adaptive processes correlated with them. These were found to be: Confinement, revitalized air, flattening of the circadian rhythms, threat of hyperbaric exposure, and sleep deprivation. Performance decrements, incidence of debilitating morbidity (including psychopathology), and decompensatory trends in crew morale appeared to be minimal during long cruises. In general, the impressions from this integrative review of this specialized section of literature is that the habitability situation in the submarine service continues to be optimal, partly because of effective psychiatric screening procedures in force, but also as a result of the caliber of leadership demonstrated by the officers and petty officers making up the crews of the submarines in the Fleet.

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INTRODUCTION

The modern atomic submarine is an excellent example of a closed ecological system. As oxygen is not necessary for the nuclear propulsion system, all of the ecological factors are contained within the confines of its 400-foot, 6-inch thick steel pressure hull. In contrast to maximum submerged periods of 72 hours possible with World War II diesel submarines, modern nuclear submarines such as the NAUTILUS and TRITON have remained submerged for 60 days or more while transiting beneath the Arctic ice cap and circumnavigating the globe. In fact, the submerged duration of each of the forty or more SSBN's (Fleet Ballastic Missile Submarines) and the almost sixty SSN's (Nuclear Attack Submarines) now operational is limited only by the amount of food, oxygen, and other vital essentials that the submarine is able to transport, synthesize or manufacture. While it is true that the size of the modern submarine has increased by about one-third, it is also true that the size of the crew has increased by approximately the same proportion. As an actual matter of fact, the space per man has decreased as a result of the introduction of a great deal of additional instrumentation necessary to propel and navigate the vehicle and to fire its torpedoes and missiles.

The objectives of this paper are three in number: First, to delineate the unique, stress-inducing aspects of the submarine environment which require equally-unique adaptation processes by each submarine crewmember; secondly, to describe the psychological and psychophysiological "make-up" of the carefully-selected submariner in terms of these specific adaptative resources; and finally, to integrate the research findings pertaining to the changes in morbidity patterns and in psychological and physiological stress indicators observed during prolonged submergence—all as they relate to overall submarine crew effectiveness.

First to be developed is an overview of the submarine environment with a view toward identifying those unique characteristics which are, or at least are assumed to be, correlated with specific adaptative mechanisms essential if the submariner is to adjust optimally to the stresses of submergence. Having delineated the major classes of environmental stressors to which the submariner must adapt, we shall then move on to a comprehensive description of his adaptative resources. Finally, the "picture" of the submarine crewmember will be "rounded out" to include an evaluation of the crewmember's effectiveness both as an individual and as an essential component of the crew which, in turn, is an integral part of the complex man-machine weapons system, the submarine.

THE UNIQUE STRESS-INDUCING FEATURES OF THE SUBMARINE ENVIRONMENT

Confinement, Restriction, Stimulus Invariance, and Related Factors

It has been estimated that there are 5 cu. yds of space provided for each nuclear submariner in an underway submarine. Whereas the untoward hallucinatory and delusional effects reported in the McGill University sensory reduction studies in the mid-fifties (Bexton, Heron and Scott, 1954) have not been observed during long "dives", there is growing evidence that the malaise, headaches, irritability and depression (albeit most often benign) observed during protracted submergence (Weybrew, 1957; Weybrew, 1962) may be the result of restricted muscular activity (Zubin, 1963) and stimulus invariance (or both) rather than the result of reduced level of stimulation per se (Weybrew, 1963).

At least two other perceptual factors may affect submariner effectiveness. In the first place, although with no acutely debilitating consequences, the close-viewing distance characteristic of the confines of the submarine may result in mild Lateral Esophoria (Faucett & Newman 1953). Also possibly symptomatic of lowered crew morale, is the occurrence of a distortion in time perception in the direction of increased positive (over-estimation) of passage of time during long submerged periods. For example, on the 75th day of the 83-day submerged circumnavigation of the world by TRITON, an observation, possible symptomatic of distorted time perspective, was the notation found on the combat center plotting board: "Time remaining on cruise, 10,200 minutes, 171 hours, 7.3 days, 0.23 months, and 0.195 years, and 0.000195 centuries." Constants to be employed to reduce each equivalent unit of time every 5 minutes of clock time were also provided! (Weybrow, 1963).

Revitalized Ambient Atmosphere

As stated earlier, as a result of the anaerobic nature of nuclear fission, the submarine is a closed ecological system completely separated from the earth's atmosphere. Thus, toxic substances such as carbon dioxide from exhaled breath (20 cubic ft/man/day), carbon monoxide largely from the combustion of smoking tobacco, aerosols, hydrocarbons from paints and lubricants may possibly become accumulative in their effects. Carhart & Pratt (1963) state "there are 200 discrete compounds existing in submarine atmospheres, albeit in low concentrations." (p. 58) Whereas the same scientists state that both gases and particulate matter "may affect greatly the performance of both man and equipment in the submarine" (op, cit, p. 58), there is no substantial evidence of direct effects on submariner performance. However, certain subjective symptomatology may be correlated with atmospheric components. These findings will be presented later on in the paper.

Threat of Hyperbaric and Radiation Exposure

Though minimal, radiation contamination is always a remote possibility. A new word has appeared in the lexicon of the phobias, namely, "bathyophobia"

defined as a morbid fear of great atmospheric pressures. Most submariners are well aware of the fact that at a depth of a thousand feet of sea water, the pressure on the steel hull is more than thirty tons per square foot. Whereas the anecdotal literature contains some suggestions that the "sitting duck" predicament of the World War II submarine during depth charging resulted in ineffective and, in some cases, acutely maladjustive behavior by some of the crew, (Duff, 1947) the speed, maneuverability and depth capabilities of the modern nuclear submarines quite probably reduces the likelihood of a need for "running silent". Thus the feeling of helplessness commonly reported by diesel submariners is much less likely to occur for the modern nuclear submariners.

Interruption of Diurnal Periodicity

During prolonged submerged missions of 60 days or more typical of SSBN's, the submariner is removed from day-night cues. The literature (Schafer, et al, 1965) supports the findings that such biological processes as heart rate, blood pressure, body temperature and quite possibly quality of performance are synchronized to such circadian cues as sunrise and sunset. The possibility exists that the desynchronization of these cycles by the imposition of 4 on 8 off work/rest schedules and by such practices as "watchdogging" may contribute to fatigue-like symptoms observed during long periods of submergence (Weybrew, 1963).

Sustained Effort, Sleep Deprivation and Fatigue

Just mentioned above was the possible contribution of disruption of circadian rhythms to fatigue symptomatology. As an example, for the nuclear submariner, in particular the SSBN crewmember, missile-ready countdowns of 1/2 to an hour are commonplace. There is some evidence (Weybrew, 1963) that the quality of sleep for some submariners worsens under these arduous work schedules after 3 to 5 weeks submerged. While unproven, high noise levels, improper lighting or any condition that adversely affects the submariners' sleep habits may in turn impair their effectiveness.

The degree of impairment from this or any other cause is not considered acute except for a few individuals whose quality of adjustment to the submarine is less than optimal for a variety of reasons including poor quality of sleep.

THE CHARACTERISTICS OF THE PERSONNEL MAKING UP THE TYPICAL SUBMARINE CREW

Having identified the major classes of stresses unique to the environment of the submerged submarines, let us now present a description of the submarine crewmember in terms of the specific resources affecting the quality of his adjustment to these conditions. Moreover, having presented a description first of the adjustive demands of the

submarine environment and second of the adjustive capacity of the submarine crewmember himself, we will then be in a position to present a meaningful assessment of the overall submarine crew effectiveness in the final section of the paper.

Characteristics of the Input Population to the Submarine Service

Since the mid-sixties the annual input to Basic Officer and Enlisted Submarine Schools in New London, Connecticut, has been 4500-5800 enlisted men and 320-450 officers. The average age of the officer input is 22 and of the enlisted men 18.5. Virtually all officers have college degrees while about 87% of enlisted men are terminal high school graduates, 6% are high school dropouts and the remainder have had some college. Whereas attrition rate varies a great deal from class to class in Submarine School, enlisted attrition for medical, academic, and other reasons has in the past 3-4 years ranged from 10% to 28% (see footnote* for a description of the Selection Ratio, a major factor affecting attrition rate). What then are some of the characteristics of this sizeable personnel input to the submarine service?

Prior to admission to Basic Submarine School each officer and enlisted man must undergo a comprehensive medical examination. Because of the nature of the submarine environment there are several criteria besides general medical health that must be met. For example, rather rigid standards for visual acuity, color perception sensitivity or any condition (respiratory or otherwise) contributing to an inability to equalize pressure of 45 PSI (pounds per square inch) in the recompression chamber to successfully execute a 50 ft ascent from the escape tank must be met. Something of the order of 5-10 percent of each enlisted class are "dropped" for the above reasons (Weybrew, 1958).

Following are some general statements grossly indicating the nature of the submariner selection criteria currently being applied to the input population. The details of the present submariner screening or selection program are presented in two publications (Weybrew, 1966, Weybrew, 1968).

Specialized Aptitudes

For the enlisted input, test score cutoffs for the Arithmetic and Mechanical Aptitude tests are set at or about the 75th percentile for the Navy as a whole. Whereas there are no comparable aptitude cutoffs applied to the officer input, a recent factor analysis (Weybrew, 1970) identified an aptitude factor highly correlated with performance in Basic Submarine Officers School.

Motivation and Attitudes

All officers and enlisted men have volunteered for the Submarine Service. Enlisted men apparently volunteer because of pay, good food and educational

*The degree to which a given assessment program is a selection rather than a screening program is a function of the Selection Ratio, that is, the ratio between the number of trained submariners needed to the number of eligible volunteers. If this ratio is above 90% (the current level) the program is of necessity functioning as a screening program.

opportunities (in decreasing order of significance), (Youniss, 1956). On the other hand, the motivational patterns underpinning an officers decision to volunteer for "subs" are: (1) satisfaction associated with being a member of the "sub" crew; (2) the adventure and challenge of a submarine career; and (3) concrete benefits such as pay, retirement plan, etc. (again in decreasing order of relevance), (Giles, Collins & Weybrew, 1971). A "custom-tailored" motivation test called the SMQ (Self-reported Motivational Questionnaire) is one of the present battery of Submariner Selection Tests in use and has been shown to have useful validity for quantifying individual differences in motivation for this branch of the service (Weybrew & Molish, 1959; Rubin & Parker, 1961). Data from the SMQ and other sources have served to demonstrate the high degree of relevance of motivational and attitudinal processes for attaining and maintaining a cohesive, productive submarine crew under a variety of stressful conditions (Weybrew, 1962; Weybrew, Molish & Ninow, 1961).

Psychiatric Screening Criteria

A number of both projective and objective personality tests have been developed for the purpose of identifying poor psychiatric risks for the Submarine Service (Weybrew, 1963). The most useful single test of this kind is the PIB (Personal Inventory Barometer) (among others), which provides an Emotional Stability Score and a Depression Score (Weybrew & Youniss, 1958; Weybrew & Kinsey, 1968). Both officers and enlisted submariner candidates with the number and severity of symptoms at percentile 90 or so in these two test score distributions have been shown to be poor adjustment risks for the service (Weybrew & Molish, 1959; Rubin & Parker, 1961). Other contraindicators of effective submariner adjustment are:

> *(1) history of loss of consciousness without any apparent reason (here a neurological examination might be indicated); (2) presence of symptoms of incipient psychoses such as hallucinations, delusions, motor disturbances or any other evidence of loss of reality contact; (3) frequency and severity of neurotic symptoms or any other remarkable signs of emotional instability, tendencies for neurotic depression and the like; (4) motivational deficiencies and/or inappropriate attitudes; and (5) presence of severe psychopathic trends such as inadequate impulse control and traits indicating reckless unconcern for the social consequences of his behavior.*

The search for these contraindicators is carried out as a part of the total assessment of each submariner candidate (officer and enlisted man) by studies of his battery profile, from interview data and from a review of the volunteer's medical and service records.

At least a start has been made to answer the question, "What configuration of personality traits describe the typical officer and enlisted submarine crewmember upon whose operational effectiveness this paper is focused. First, a factor analysis of one Submarine School Class of officers (N-150) delineated 5 factors describing submarine officers (Weybrew, 1970) listed as follows:

> *Factor I. Trait pattern emphasizing motivational and attitude parameters; Factor II, a general Temperament Dimension; Factor III. Special Aptitudes; Factor IV, Politico-*

Economic Interests; and Factor V, Focused Theoretical Interests. Factors I and III only appear to be correlated with Submarine School performance. Employing the same statistical method but this time based largely upon underway ratings, a like number of Factors were extracted from both crews of one SSBN (Weybrew, 1962). Accordingly, the five dimensions describing the enlisted submariner were: Factor I, a Motivation--Attitude Dimension; Factor II, Emotional Stability; Factor III, and Factor IV, mixed bipolar factors related to Military Appearance, Emotional Stability and Quality of Performance, and Factor V, Leadership Potential. Unlike the Submarine Officers Factors, however, all of the enlisted factors were correlated with submariner effectiveness.

MORBIDITY PATTERNS AND PSYCHOPHYSIOLOGICAL CHANGES AS INDICES OF SUBMARINER EFFECTIVENESS

Before focusing upon the morbidity and change problem under operational conditions; it might be advisable to consider the size of the submariner population following Submarine School graduation. Table 1 contains approximations of the number of each class of submariners that is operational and the approximate crew size of each, while

TABLE 1

Estimates of Numbers of Operational Submarines and Allowed Billet Strength by Type of Submarine

	SSBN	SSN	Diesel
No. of Operational Submarines	41	58	60
No. Under Construction	0	5	0
Allowed Billet Strength			
Officers	14(10%)[a]	9(9%)	9(12%)
Enlisted Men	125(90%)	92(91%)	64(88%)
Estimated Totals in Submarine Service	12K	6.3K	4.2K

[a] 2X, since each SSBN has a Blue and Gold crew assigned.

Table 2 contains gross approximations to the distributions of occupational specialities comprising the crews of each submarine class.

Two observations concerning these tables appear in order, namely, that the crew size for SSNs and SSBNs has increased by about 50% and 100% respectively (as compared to diesels) and at the same time the proportion of electronics, engineering and ordnance ratings has increased by a factor of at least one and one half. This requirement for an ever-increasing proportion of highly specialized technicians within the crew of a modern nuclear submarine has become an accepted fact by personnel managers generally. However, there is evidence in both the older submarine literature (Scott, 1952) and in the more recent literature (Weybrew, et al, 1961) that suggests that as a submariner's role becomes more

TABLE 2

Estimates of the Distribution of Rating or Skills Categories Constituting the Crews of SSBN, SSN and Diesel Submarines

Specialty Groupings	SSBN (N=125)[a] Percent	SSN (N=92)[a] Percent	Diesel (N=64)[a] Percent
Electronics & Precision Instr. Group	20	18	6
Engineering & Hull Group	31	39	22
Ordnance Group	19	9	19
Deck Group	9	14	14
Administrative & Clerical Group	6	6	10
Medical Group	1	1	1
Steward Group	2	2	5
Non-rated Men	12	11	23

[a] These are gross estimates as both billet allowance and on-board count vary from time to time.

congruent with the status imposed by the system, the effectiveness of the individual as well as the crew as a whole increases. This relationship provides rather obvious implications for long range planning in the area of submarine personnel management.

Behavioral and Physiological Changes During Prolonged Submerged Missions

Since the years between the launching of the first nuclear submarine NAUTILUS in 1954 and the first Fleet Ballistic Missile mission in 1960, an ever-present question among submarine medical researchers generally has been and still is "What is the maximum duration of a submerged mission before decompensation, performance decrements and debilitation begin to occur within the members of the submarine crew?" Bearing on this question are some brief comments based upon a number of laboratory and field studies completed during that epoch-making era and subsequent to it.

Vigilance

It would seem to be a fair assumption that the accuracy of radar and sonar target detection and the ability to read the dials and manipulate the controls necessary to operate a nuclear submarine are effected by the "readiness" of the men to respond to signals of various kinds. In the context of an outline of the major problem areas anticipated in the FBM program, Levine (1958, p.1) states, "Even if the atmosphere is such that men can live in a submerged submarine for periods of 60 days or so, the subtle and more psychological antialertness factors would still be present."

Observations made during a 30-day simulated war patrol in a Guppy-Snorkel submarine indicated a tendency toward reduced alertness, inability to concentrate, and a general reduction in excitation level as the cruise progressed (Ritch, 1948). Similarly, self-reported data collected daily during the first prolonged (11 days) submerged cruise of the NAUTILUS suggested the possibility that reduced alertness was symptomatic of the majority of the 20 men included in the sample (Weybrew, 1957). However, daily measures of critical flicker frequency thresholds indicated no significant changes in visual sensitivity during the same submerged period. Similarly, plots of means of perceptual spans for numbers and letters measured biweekly during eight weeks of incarceration in an evacuated submarine showed no decrement (Faucett and Newman, 1953).

In summary, the significance of the problem appears to have been recognized but the results now in at least appear to be equivocal as to the severity of the effects of long exposure to these conditions.

Psychomotor Performance

Most of the studies in the area of submarine psychology have been designed to determine grossly whether performance efficiency is in fact maintained during prolonged periods of submergence. One early study involved the confinement of 22 men to a submarine for 60 days (Faucett and Newman,

1953). The performance measures were the Minnesota Manual Dexterity Test, a two-hand tapping task, a letter-cancellation task, and the seven subtests of the MacQuarrie Test for Mechanical Ability. Plots of means for research test or subtest score showed some significant changes between sessions but no definite trends over the period of confinement. Where performance did decline between sessions, self-reported motivation simultaneously also declined, suggesting that the observed decrements may have been due to deteriorating motivation rather than to any direct effect on the experimental conditions upon psychomotor processes. This finding points up the very serious limitation to this kind of experimentation, namely, the difficulty in determining the difference between capacity and performance, that is, what the person "will do" as compared with what he "can do". In the jargon of the submariner, the "will do"/"can do" ratio as an output criterion for a crew member day in and day out is very much to the point.

The ancedotal literature (Duff, 1947) is replete with reports of increased tension among the crewmembers observed during prolonged submerged cruises. Estimates by means of scores obtained from a standard stylus-in-hole apparatus, the level of muscular tension of 22 subjects during a 60-day simulated submergence decreased sporadically at the outset then maintained the approximate level of the control period throughout the remainder of the experiment (Faucett and Newman, 1953). Similarly the mean hand-steadiness scores obtained from 30 men from the crew of the NAUTILUS were plotted by day during an 11 day submerged cruise (Weybrew, 1957). These data suggested a trend toward increased muscular tension from the fifth day submerged until the end of the cruise. In short, the level of muscular tension does change during submergence. The literature fails to indicate, however, whether the change in tension is related to performance efficiency as the submergence progresses.

A recent study conducted during a 56-day submerged mission of an SSBN was designed to assess trends in psychomotor performance (measured by a two-hand tapping task) and in spatial perception (MacQuarrie Test Mechanical Ability) as a function of passage of time (Johnson, 1971). Briefly, the results based upon data collected from 14 enlisted crew members indicated that, following a brief learning period, the curve of mean scores plotted by week-submerged reached a plateau, holding constant or at least showing no decrement, for the duration of the 8 week mission. This was true at least for the MacQuarrie Mechanical Ability data and for the two-hand tapping test also until the 6th week of the patrol at which time the psychomotor performance of the crewmen sample improved significantly (5% confidence levels) as indicated by an increase in mean tapping score. Although unproven by this study, the impression is that this increment represented what has been called the "end spurt", or in Navy jargon, the outset of "channel fever". In any case, the most parsimonious explanation of this change is motivational, whatever its cause.

Emotional Response Patterns as Denoted by Autonomic, Endocrinological and Subjective Indicators

In conducting the following studies and interpreting the resulting data it was hypothesized that individual differences in the quality of adjustment to a stressful environment are intricately related to a person's characteristic modes of adjustment, his "life style", which includes his repertoire of modes of emotional expression. One of these modes of emotional behavior involves patterns of autonomic and endocrinological processes, the nature of which probably depends in part upon hereditary predispositions and early developmental history particularly as affected by long term autonomic conditioning.

Although in various places in the submarine literature mention is made of the probable changes in autonomic function resulting from submergence (for example, Essex, 1948), very little experimental data are available. In so far as autonomic reactivity can be inferred from the function of the adrenal system, significant drops in eosinophile counts were reported during eight weeks of simulated submergence (Faucett and Newman, 1953). Moreover, a significant fall in blood pressure during submerged exposure to an atmosphere containing from 2 to 4 percent carbon dioxide was reported by Schaefer (1959). A decline in mean (N=30) radial pulse the first five days and a rise in the same measure during the remaining five days of the submerged cruise aboard the NAUTILUS were also reported (Weybrew, 1957).

However, measures of blood pressure and pulse rate changes and recoverability obtained by means of the U.S. Navy "step-up" procedure were collected from 28 men during a 60-day simulated submergence (Faucett and Newman, 1953). There were no significant fluctuations in these variables reported in this study.

Two multivariate laboratory studies and one underway-submerged study, all involving submariner subjects, provided some empirical support for the relevance of peripheral autonomic indices for predicting submariner adjustment (Weybrew and Alves, 1959; Weybrew, 1962; Weybrew, 1964). Three statements from a paper summarizing these studies suggest some tentative conclusions as follows (Weybrew, 1965, p. 12):

1. As inferred largely from the resting level of palmar electrodermal conductance (EDC), low excitation level (low EDC level) is associated with favorable trait ratings made during submariner training, but is correlated in the opposite direction for ratings obtained during prolonged submergence.

2. Similarly, the data from the two major studies are consistent inasmuch as favorable adjustment ratings made on shore-based personnel are associated with high EDC increases to, and more complete recovery following, stress. In disagreement, however, is the fact that low, not high, EDC displacement during laboratory-induced stress was associated with favorable ratings during prolonged submergence.

3. All of these experiments involving submariners suggest that the more completely the ANS displacement resulting from laboratory-induced stress is recovered the greater the likelihood to receive favorable adjustment ratings during long submerged missions.

In brief, the data reported in these studies argue that reliable measures of autonomic responsivity to contrived stress situations are correlated with adjustment ratings but possibly in different directions from one set of environmental circumstances to another. ANS recoverability or resiliency on the other hand seems to be positively related to adjustment adequacy across different kinds of adjustment situations. All in all, the possibility of employing ANS measures obtained under laboratory conditions to predict individual differences in emotiality under submerged conditions seems plausible at the very least.

Most of the studies aimed at evaluating behavioral changes during prolonged submergence have relied heavily on self-reported data. What has this kind of information contributed as indicants of the behavioral effects of prolonged submergence?

Some relatively recent data of this kind were collected as a means of evaluating changes in the quality of adjustment to submerged conditions during the TRITON world circumnavigation (Weybrew, 1963). Since the duration of the submergence was approximately three months, a duration similar to that planned for the FBM submarines, the circumnavigation provided a unique opportunity to observe changes in the psychological status of the man, changes that may be applicable to the FBM situation.

A list of adjectives or behavioral statements designed to tap moods, self-perceived efficiency, interpersonal attitudes, and the like were compiled for use in the TRITON study. Examples of these items are: tense, happy, irritable, can't concentrate, energetic, difficult to breathe, tired out, etc. — 50 items in all. Each man of a sample of approximately 40 men from the crew of the TRITON indicated daily the degree to which each of these items described himself at that time. A multiple-category response format was used by the men to indicate the relative significance of each item on each day of the cruise.

A factor analysis resulted in the removal of three centroid factors from the 56x56 correlation matrix. The first factor, loaded by virtually all of the variables including one of the six atmospheric variables (barometric pressure) was without question a general factor accounting for a large portion of the communalities. The loadings for the most significant variables identifying the remaining two factors are presented in Table 3 and 4. The second factor (F_{T_2}) was tentatively labled a "Composite Morale Indicator" (Table 3), whereas the third factor (F_{T_3}) received the tentative label "Covariants of Atmospheric Variables" (Table 4).

Scores for each of the 79 days for the two factors delineated in Table 3 and Table 4 were estimated and plotted (Figure 1) in order to shed some light on the question: What environmental conditions were coincident with (or possibly causal for) the factor fluctuation from day to day?

Before some environmental conditions are suggested that may have affected the level of the factor scores in

TABLE 3

Major Identifying Variables for the Second Factor (F_{T_2})

F_{T_2} Tentative Label: Composite Morale Indicator

Variable Number	Loading[a]	Content[b]
7	0.88	Morale low
22	0.76	Fed up
10	0.70	Irritable
37	0.68	Homesick
15	0.65	Don't feel like talking
13	0.64	Annoyed
24	0.64	Disinterested
41	0.64	Feel like giving up
11	0.63	Mouth dry
4	0.59	Bored stiff
5	0.58	Don't feel like doing anything
19	0.58	Daydream a lot
40	0.58	Headachy
43	0.58	Uncomfortable
50	0.56	Frustrated

[a] Factor has been reflected.

[b] Takes into account the sign of the loading.

TABLE 4

Major Identifying Variables for the Third Factor (F_{T_3})

F_{T_3} Tentative Label: Covariants of Atmospheric Variables

Variable Number	Loading	Content[a]
56	1.00	Hydrogen (0/0)
51	0.60	Barometric pressure (mm)
45	0.53	Difficult to sleep
53	0.50	Carbon dioxide (0/0)
6	0.47	Inefficient
52	0.46	Oxygen (0/0)
30	0.45	Jittery
28	0.44	Anxious
34	0.43	Excited
36	0.43	Clutched up
42	0.43	Feel closed in
14	0.42	Joints and limbs tired
43	0.41	Uncomfortable
44	0.41	Don't feel like eating
25	0.40	Tight or hot feelings in stomach

[a]Takes into account the sign of the loading.

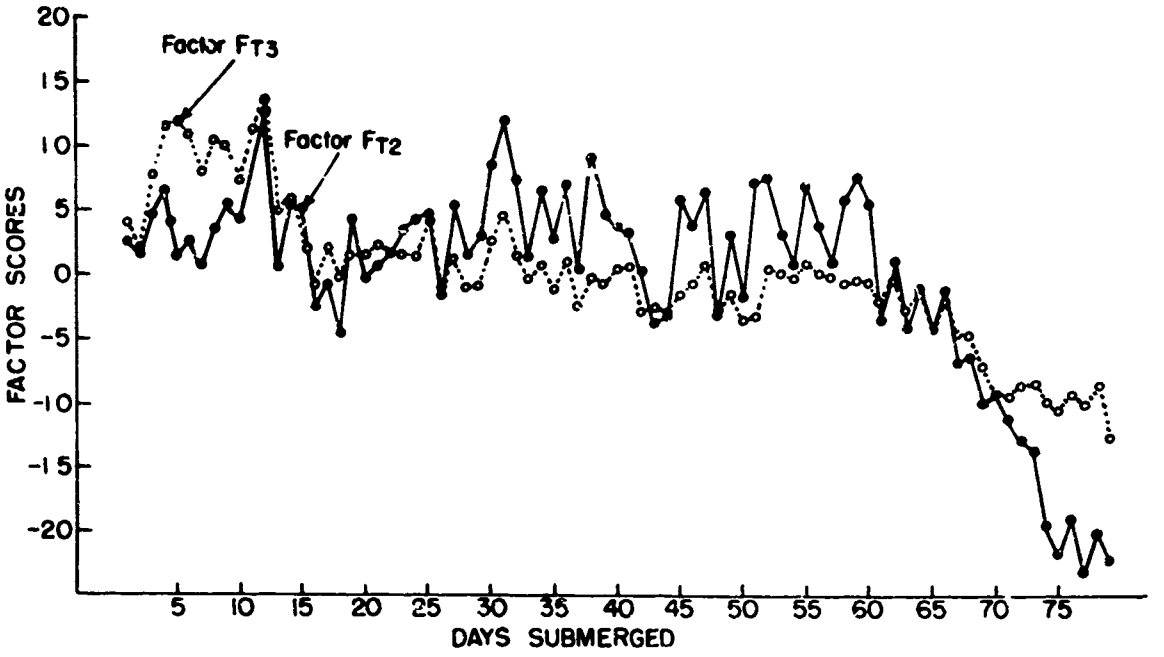

Figure 1. Factor Scores Plotted by Days Submerged During the World Circumnavigation of TRITON (SSN 586) (Weybrew 1963)

Figure 1, it should be pointed out that a high positive score in F_{T2} (Table 3) indicates reduced morale and presumably less favorable adjustment. Similarly, high scores on F_{T3} (Table 4) also appear to be indicative of less favorable adjustment. In addition, the structure of F_{T3} (Table 4) suggests the possibility that atmospheric conditions at least tend to covary with (and could be causally related to) the subjective indices used in this study.

Several general findings emerge from an inspection of the curves in Figure 1. First, adjustment adequacy as indicated by troughs in both curves are found wherever a landfall is approached. Accordingly, troughs are seen on the tenth day, St. Peter's and Paul's Rocks; on the twentieth day, Cape Horn; on the twenty sixth-day, Easter Island, and so on (Beach 1960). Second, adjustment is favorable on Sundays (days 13, 20, etc.) and least favorable on the weekly field days (complete clean-up of ship), as indicated by peaks in the factor curves, for example, days 11, 18, 25, 32, etc. Third, the subjective effects of a smoking curfew may have been reflected by the peak in the F_{T2} curve coinciding with the fifty-ninth day. Finally, the well-known "end effect" mentioned previously in the section on psychomotor performance appeared to have set in approximately two weeks before the end of the cruise.

These findings suggest certain environmental conditions that appear to affect the morale and the general adjustment status of the personnel.

TABLE 5

Percentage of Submerged and Shore-Based Crews
Changing Their Response to the Question:

Do You Think the Submarine Atmosphere is Dangerous to Your Health?

	Change toward "Less Danger"	No change	Change toward "More Danger"
Submerged Crew (N=101)	7%	38%	55%
Shore-Based Crew (N=101)	16%	54%	30%

With df=2, p of $X^2 < .01$

Motivational and Attitude Changes

Most of the studies designed to delineate and assess the effects of long submerged missions have consistently demonstrated among other findings, that individual motivation and, concomitantly, group morale often declines as the cruise progresses (e.g. Weybrew, 1957; Weybrew, 1963). Attitudes, which are "sharply" polarized motives, also are modified during submergence as demonstrated by comparing the submerged SSBN crew simultaneously with the matched shore-based crew (N=125) in terms of attitude change (Weybrew, Molish and Ninow, 1961). While differences between the submerged and shore-based groups in terms of changes in response patterns on 89 attitude test items were examined in the study, the results of the analysis of one item only is presented as an example in Table 5.

Morbidity Patterns During Extended Submerged Missions

It should be obvious from the preceeding discussion that the submarine environment is indeed unique in several respects. The question arises as to whether there is in fact morbidity patterns endemic to submariners incarcerated in a sealed-off environment for sixty days or more.*

The most updated epidemiological data pertaining to submarines and sub-

*The Naval Submarine Medical Research Laboratory in a so-called Lorgitudinal Health Study currently in progress is focused upon the classes of disease indigenous to the submarine environment.

mariners has its origin in a paper by Wilken (1969). The "population-at-risk" reported in this monograph was estimated by the author as 3,000,000 submerged man-days. This calculation was based upon the fact that the paper contains data from the trip reports of 360 POLARIS patrols, averaging 60 submerged days per patrol. Since there are approximately 140 men per crew, another way of describing the sampling procedure would be in terms of man-patrols, in this case, approximately 50,000.

At the outset, a categorical statement was made regarding the general health of the SSBN crewmen. Thus, Wilken (1969) states (page 1) "Indeed, 82 of the 360 patrols reported no sick days for the entire patrol!" The author hastens to state however, that 14 medical cases "were of such consequence as to necessitate the interruption of patrol to transfer the patient at sea." (ibid). Also four deaths occurred during these patrols.

Infectious Diseases

Since the submerged submarine must maintain watertight integrity at extremely high pressures (45 PSI, relative pressure for every 100 feet of sea water), the flora and fauna, pathogenic or not, taken in when the gaskets are sealed are trapped therein. The first question then pertains to the incidence, severity and epidemiological significance of infectious diseases reported during long submerged cruises. Respiratory diseases, as expected, are reported the most frequently of all general medical conditions. With incubation periods of 7-11 days, colds appear in 70-90% of the crew early in the mission, then tend to disappear thereafter. In total, diseases of the ear, nose and throat accounted for 107 cases resulting in 297 sick days during the 360 patrols.

Other respiratory conditions (upper respiratory infection, nonspecific, pneumonia, bronchitis, pleurisy and pneumothorax) occurred during the 360 patrols in 111 cases in 433 total sick days (Wilken, 1969, page 12)*. Influenza occurred in 74 cases (150 sick days), infectious hepatitis in 7 cases (187 sick days) and infectious mononucleosis in 18 cases (162 sick days). Gastric conditions (gastroenteritis and gastritis) were the diagnoses in 97 cases for a total of 197 sick days. Finally, medical conditions, loosely grouped as urological, accounted for 56 cases and 275 sick days.

Surgical and Orthopedic Problems

In contrast to the World War II diesel submarines which were limited by air revitalization capacity and battery power to submerged periods, rarely exceeding 72 hours, the modern SSN and SSBNs are capable of submerged periods limited only by the amount of vital essentials that can be transported or manufactured. Or, as one nuclear submariner facetiously put it, "the nuke sub needs only to surface every 4 years — for the men to re-enlist!" Consequently, orthopedic and surgical cases resulting from hasty descents of crewmen from the superstructure of a surfaced "sub" to its internal recesses

All of these data are contained in the Wilken monograph (1969) which reference will be omitted hereafter.

before they "take her down" have been virtually eliminated. For example, during the 360 FBM patrols being discussed, 100 surgical cases, totalling 532 sick days, were reported. Interestingly, appendicitis, treated non-surgically, accounted for almost 50% of of the total sick days. Orthopedic cases specifically, on the other hand, occurred in 109 cases, with 560 sick days resulting. Not unexpectedly, about 40% of these sick days were accounted for by back-related conditions or injuries.

Psychiatric Problems

The incredibly small incidence of psychiatric casualties during World War II patrols amounting to 56 out of 126,160 man-patrols attests to the apparent insignificance of this type of problem (Duff, 1947). Similarly, Ninow (1963) reported an incidence of psychiatric referral from the operational submarine force as 20 per thousand. Of these more than half were classified as character or personality disorders and another fourth as neurotic disorders. As a rule approximately two-thirds of the submariners referred for psychiatric evaluation (circa 13 per 1,000 referrals) are disqualified for additional submarine duty.

Returning again to the Wilken (1969) study involving 360 FBM patrols, it is seen that 192 psychiatric cases were reported, 136 of which were described as anxiety reactions. However, only 69 sick days resulted from these 192 cases and of these, 52 sick days were accounted for by 2 submariners who developed acute psychopathology early in a patrol. This remarkably low sick-day record results from the fact that most of the psychopathology characteristically involves mild emotional (often neurotic) disturbances, usually situational in nature and hence transient, and, which, in most cases, are controllable by the application of mild chemotherapeutic (minor tranquilizers) and psychotherapeutic techniques.

A reliable statistic indicative of the magnitude of the decrement in submarine crew effectiveness resulting from illness and incapacitation of one kind or another is difficult, if not impossible, to obtain. Epidemiological studies generally and including those dealing with military data, for example, (Plag & Phelan, 1970), have tended to agree on one issue, namely, that a relative small proportion of the population-at-risk most often accounts for a disproportionately large fraction of the sickness. For example, in the study cited immediately above, 8.7% of the more than 6,000 enlisted Navy men included in the sample accounted for 34.2% of all illness. Hence, in the morbidity statistics cited in this paper, the number of cases is of course not to be construed as equivalent to the number of sick crewmen. This is true because many of these cases are recidive, resulting from relapses or reoccurrences of illness or incapacitation. Obviously, the number of man-days lost because of sickness occurring during a submerged patrol of 60 days for example is a useful index of crew effectiveness. Plag and Phelan (op. cit.) state that the average enlisted man loses approximately 1 per cent of his time by sickness, or stated another way, the Navy enlisted man averaged 4 sick days per year. Although Wilken's (1969) data

does not lend itself well to this kind of analysis, if one accumulates sick days across all illness categories something of the order of 2,500 sick days is arrived at for 2,000,000 man-days on submerged patrol. Although not cited here as an accurate epidemiological fact, this gross analysis nonetheless suggests an incidence rate of something less than 2 sick days per 1,000 man-days on patrol.

It was mentioned earlier but may bear reiterating since it tends to support the incredibly low morbidity rate estimated above, that Wilken (1969) reported more than 11,000 man-days on patrol with no sick days whatsoever appearing in the ship's log. There seems little doubt that submarine crew effectiveness in general is not reduced significantly by illness.

SUMMARIZING COMMENTS PERTAINING TO THE FACTORS TENDING TO MAXIMIZE SUBMARINER EFFECTIVENESS

Ecologists quite generally accept the fact that biological adaption is a complex function of (1) the nature and severity of the imposed environmental stresses and (2) the adaptive capacity of the persons involved. Accordingly, this paper has focussed upon the quality of the submarine crewmen's adaptation to the unique stresses of the submarine. While the supporting data are sparse in certain areas, nonetheless, a gross assessment of the results already in the literature suggests that there is little, if any, evidence for seriously debilitating physiological or psychological effects of exposure to submerged conditions of 60 days duration. Neither are there any remarkable morbidity patterns clearly endemic to the submarine environment for the same submerged period. Why is the habitability situation within the Submarine Service, as it seems, so favorable?

In the first place, the modern nuclear submarine not only has incorporated the most advanced designs in the fabrication and function of the air revitalization, fire control and navigation systems but also has benefited from the application of modern human engineering concepts aimed at providing ample "hotel accommodations" and "creature comforts", presumably essential for attaining and maintaining crew morale and "esprit de corps". Other factors accounting for the favorable livability situation in the "sub" service, though implied in several places in the preceeding discussion may be reiterated here for the purpose of clarification: (1) Efficient personnel screening or selection procedures; (2) Group interaction processes tending to produce cohesive submarine crews; and (3) The quality of leadership intrinsic to and presumably essential for the integrity of the crew.

Efficacy of Submariner Selection Procedures. Quite likely to a significant degree, the optimal quality of the submariners' adjustment results from first, the comprehensiveness of the medical and psychiatric screening procedures designed to identify poor adjustment risks for the service. Secondly, another factor inextricably tied in with the selection process itself has to do with the motivational patterns underpinning the officer or enlisted man's

decision to volunteer for this branch of the Navy in the first place. As a result, each of the 5,000 enlisted and 400 officer annual input into the service has a high probability to adapt optimally to the stresses of prolonged submergence.

Cohesive Effects of Social Motivation. Identified by the much-coveted dolphin, submariners characteristically demonstrate in a number of contexts the self-perceived significance of their role as a submariner. This fact is inferred not only from the closely-knit subgroups identified with rating specialities within the crew itself, but also from the integrity and functional significance of submariner families well-coalesced within the civilian communities adjacent to submarine-related shore activities.

Charismatic Qualities of Submariner Officers and Petty Officers. Following the first successful passage beneath the polar ice cap by the Submarine Nautilus in 1958, the Medical Officer, member of the Nautilus crew, stated his opinion that the effectiveness of the crew during the treacherous crossing was in a large measure the result of the manner in which the officers and petty officers channelized and integrated individual crew member effort into team effort so that the mission came to a triumphant conclusion. Though difficult to assess, leadership potential of the kind typically found in submarine crews quite likely has components originating both from "nature and nurture". Whatever their source, these personal qualities appear to be essential for the maintenance of submarine crew effectiveness during long submerged missions.

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